Title: Physics of Model Rockets

Brief Overview:

This unit is intended as a culminating activity for Physics students who need a "real-world" connection. The students build a simple model rocket and compare its performance to predictions. Their prediction can involve the use of conservation of momentum, conservation of energy, Newton's Laws of Motion, kinematics formulas, and friction.

Links to Science Standards:

- **Curriculum**
  Students will use the ideas of Physics in solving a problem in Aerospace Engineering.

- **Habits of Mind**
  Students will compare experimental results (the actual maximum altitude of their model rockets) with those of theory and attempt to explain the difference.

- **Attitudes**
  Students will have a chance to construct and test a device which behaves in a manner consistent with their predictions.

- **Science Processes**
  Students will use balances to find the mass of their rockets and calculators to calculate velocities and distances. They will measure the height of their rocket flights through triangulation using protractors and tape measures or similar devices.

- **Application**
  Students will apply their theoretical view of the rocket flight to make predictions of what would happen if certain conditions were to change. For example, how much higher would a rocket go with a B engine instead of an A, or what effect would launching on the moon have on maximum altitude?

Grade/Level:

Grades 8-12

Duration/Length:

This activity should take 5-7 days. 2-3 of those are used to construct the rocket, 1-2 to consider theory and 1-2 to fly. The flights can take longer depending on the size of the class and student interest.

Prerequisite Knowledge:

Students should have working knowledge of the following skills:

- Calculating impulse
- Calculating kinetic energy and gravitational potential energy
- Applying Newton's Laws
- Using the kinematics formulas

Objectives:

Students will:

- work cooperatively in groups to construct and fly model rockets.
- apply physics principles to predict the performance of a model rocket.

Materials/Resources/Printed Materials:

- Model Rocket kits (simple units from Estes or another source) and a Launcher.
- Resource Sheet 1

Development/Procedures:

- Discuss with the students how a model rocket (or a real one such as the Shuttle) flies. Involve as much theory as necessary to get interest going.

- Begin construction of the model rockets. If you are organized, the basic construction can be mostly finished in one period. The next day finish construction and begin painting the rockets. Use spray cans of paint. BE CAREFUL! Painting is messy so it is best accomplished in a hood or outside away from anything which can be damaged by over spray. A coat hanger can be bent into a stand to hold the rocket on the ground so students' hands aren't as likely to become rainbow hued.

- Once the rockets are completed, go through the calculation of predicted speed and altitude (Resource Sheet 1). Do the calculation for the smallest engine which you will fly. Recommend starting with an A engine (or a 1/2 A for younger students) in small rockets.

- Discuss with the students how to determine the altitude of their model rocket flights. Develop a scheme for using triangulation to measure altitude. Gather the necessary materials for such measurements.

- Fly the rockets for the first time. Keep a log of each flight with the name of the student and altitude and time of flight data. This gives an immediate means of comparing results and will start much friendly competition for longest time of flight and highest flight.

- After the first flights, come back to theory. Discuss actual versus theoretical altitude. Ask the students to predict what will happen with a stronger engine, then actually do the calculation. Many will be surprised that doubling impulse nearly quadruples altitude.

- Return to flying. For second and later flights try full A and B or (if you dare) C engines.

- HAVE FUN! You may find yourself with a new hobby.

Performance Assessment:

1. Have each student do a complete performance calculation on their own rocket. They should mass their rocket and the full engine. They can then fly the rocket, mass their empty engine and complete the calculation. If you wish, talk to the students about possible friction models and have them try to calculate coefficient of drag for their rocket from their data. This activity can then be graded as you would any lab.

2. To spur interest offer prizes (e.g., use bags of M&M's) for the longest first flight or best paint job.

3. A problem or two based on rocket flights can be incorporated into homework assignments.

4. A problem based on rocket flights should be incorporated into the unit test that follows these activities.

Extension/Follow Up:

- This is but a start on what you can do with model rockets. Suggest that you acquire and read the Estes Educator packets listed below.

  Physics and Model Rockets - A Curriculum for Grades 8.9.10 & 11

  Mathematics and Model Rockets - A Curriculum for Grades 5-12

  These are available from: Estes Industries
  1295 H Street
  Penrose, CO 81240

- The rocket which is used in the example is available from:

  bb co.
  P.O. Box 236
  Horntown, VA 23395
  (757) 824-0514
  bbco@shore.intercom.net

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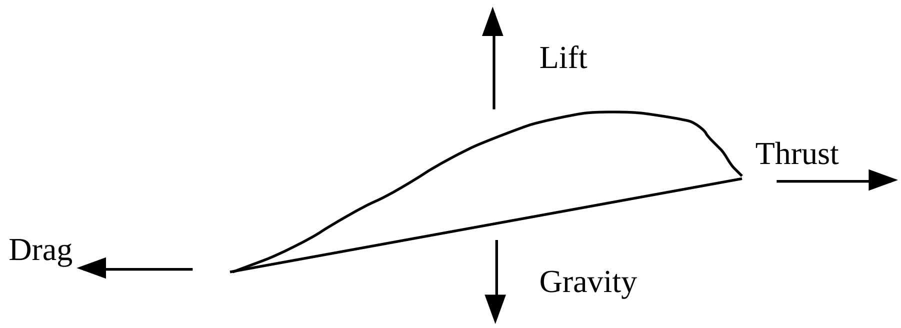
Basics of Model Rocket Flight

The Four Aerodynamic Forces:

The four forces are illustrated on the drawing of a wing below. They are lift, gravity, thrust and drag. In the case of a flying airplane these forces are in balance when the plane is in level, steady speed flight. For a rocket, the forces are rarely in balance.

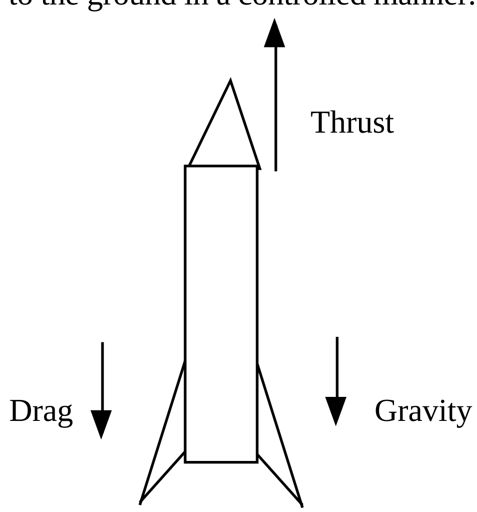


The flight of a rocket involves the same forces but in a different mix. A rocket's flight can be thought of in three phases, with different conditions during each. These phases are:

1. Thrust Phase - During this phase the engine is producing thrust and the rocket is accelerating upward.

2. Coasting Phase - After the engine burns out but before the recovery system is deployed. During this phase the rocket continues to rise but is decelerating.

3. Recovery Phase - After the recovery system (parachute or other device) deploys the rocket returns to the ground in a controlled manner.



A typical model rocket during Thrust Phase. After the engine stops, thrust goes to zero.

Calculations

I. Thrust Phase: During this phase the rocket accelerates to its maximum velocity and begins its ascent. We can calculate V_{max} and d_T for the thrust phase as follows.

A. Engines are rated in terms of impulse this way:

Engine Code	Impulse (Ns)
1/4 A	0.000 - 0.625
1/2 A	0.625 - 1.250
A	1.250 - 2.500
B	2.500 - 5.000
C	5.000 - 10.00
D	10.00 - 20.00

Since impulse equals change in momentum, we can calculate the maximum velocity of the rocket (in the absence of friction) from

$$\text{Impulse} = m \bullet \Delta V \qquad \text{and since } V_o = 0$$

$$\text{Impulse} = m \bullet V_f \qquad \text{so. . .}$$

$$V_f = \frac{\text{Impulse}}{m_{avg}}$$

Note that since the rocket changes mass during the burn we use average mass.

B. Engines are also rated in terms of Thrust. For example an A8 - 3 engine has a total impulse of 1.25 to 2.5 Ns (that's the A), an average thrust of 8 N (the 8), and a time delay of 3 seconds after burn out until it backfires to deploy the recovery system.

To calculate altitude at the end of the Thrust Phase (call it d_T)

$$d_T = V_{avg} \bullet t \quad (1) \qquad \text{where } V_{avg} = V_f / 2 \quad (2)$$

$$\text{and } t = \frac{\text{Impulse}}{\text{Thrust}} \quad (3)$$

Have the students calculate (2) then (3) then (1). Or you can substitute (2) and (3) into (1) to derive

$$d_T = \frac{\text{Impulse}^2}{2\, m_{avg} \bullet \text{Thrust}}$$

but it makes more sense to the kids to work it out the first way.

II. Coast Phase: Here the engine is off and the rocket drifts to a stop. Some guesswork comes into play here. We continue to ignore friction and assume that the rocket coasts to a stop under the influence of gravity. So we calculate the time of coast and then the distance traveled during coast as follows.

$$t_c = V_f / g \qquad \text{where, of course, } g = 9.8 \text{ m/s}^2.$$

Then

$$d_c = V_{avg} \cdot t_c \qquad \text{with } V_{avg} = V_f / 2 \text{ as before.}$$

An alternate approach to this section is to consider conservation of energy. Letting the rocket's KE at burnout convert into GPE gives

$$\frac{1}{2} m_{avg} \cdot V_f^2 = m_{avg} \cdot g \cdot d_c \qquad \text{or. . .}$$

$$d_c = V_f^2 / 2g$$

III. Adding the two distances together gives an estimated maximum altitude to be reached by the rocket.

$$d_{max} = d_T + d_c$$

IV. Here is a sample calculation using a bb co. Streaker rocket and an A8 - 3 engine.

Mass of the rocket without engine = 17 grams
Mass of the new engine = 14 grams
Mass of the spent engine = 8 grams

Thus $m_{avg} = 17 + \frac{(14 + 8)}{2} = 28$ grams or 0.028 kg

So. . . $$V_f = \frac{2.5 \text{ Ns}}{0.028 \text{ kg}} = 89 \text{ m/s}$$ by the way, that's 200 mph!

and. . . $$V_{avg} = \frac{89 \text{ m/s}}{2} = 44.5 \text{ m/s}$$

$$t = \frac{2.5 \text{ Ns}}{8 \text{ N}} = 0.31 \text{ sec}$$

$$d_T = 44.5 \text{ m/s} \cdot 0.31 \text{ s} = 13.8 \text{ m}$$

and. . . $$t_c = \frac{89 \text{ m/s}}{9.8 \text{ m/s}^2} = 9 \text{ sec}$$

$$d_c = 44.5 \text{ m/s} \cdot 9 \text{ s} = 400 \text{ m}$$

for a total altitude of

$$d_{max} = 13.8 \text{ m} + 400 \text{ m} = 414 \text{ m}$$

Actual values are more nearly 200 m or so. Discuss with your students how drag affects each stage of the flight and reduces maximum altitude. You may have noticed that I also ignore the reduction in impulse due to the work of gravity during the thrust phase. The numerical values are rather small but you may want to factor them in for more detail. Also the actual burn rates of the engines are not constant. The data sheet which accompanies your engines will show you the actual thrust vs time curve. Also consider the effect of the backfire and deployment of the recovery system after only 3 seconds of coasting.